



**M** CUBED TECHNOLOGIES, INC.  
NEW MATERIALS FOR A NEW AGE

# **Low CTE & High Stiffness Composites with Directly Polishable Surfaces for Mirrors and Structures**

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## Presentation Outline

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- ◆ Overview of M Cubed Technologies: Materials, Capabilities & Process.
- ◆ High Specific Stiffness Composite Development Program
  - Reaction Bonded B<sub>4</sub>C (RBBC-751)
  - Diamond Reinforced Reaction Bonded SiC Composites
  - Formation of Machineable Surfaces on Diamond Reinforced composites (Patents Pending)
- ◆ Summary & Conclusions



# M Cubed Technologies:Facilities

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***Monroe, CT: 48,000 FT<sup>2</sup>  
Manufacturing & Materials  
Development***

***Tokyo, Japan: Business  
Development Office***



***Newark, DE: 140,000 FT<sup>2</sup>  
Manufacturing & Materials  
Development***



## Facilities: Overview

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- ◆ M Cubed Technologies – Monroe CT Site, ~ 50,000 sg.ft.
  - Design & Analysis: CAD, CAM, (ProE, ProM, ProMechanica, Virtual Gibbs, SurfCam)
  - Research & Development: Materials Development and Characterization.
  - Advanced Machining (cutting, grinding, lapping, EDM)
  - Clean room Assembly (Class 100 benches; Class 1,000 and 10,000 rooms)
  - Inspection (12” and 18” fully instrumented laser interferometers)
  - Manufacturing Focus: Precision Products (Reaction Bonded)
- ◆ M Cubed Technologies – Newark DE Site, ~ 140,000 sg.feet
  - Design & Analysis:
  - Research & Development: Materials Development and Characterization laboratories.
  - Manufacturing Focus: Metal Matrix Composites & Ceramics.(Armor & Industrial)



## Manufacturing Capabilities: RBSC Products

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**Capacity and capability exists at CT and DE facilities to produce small to large size products for precision applications.**



### Infiltration:

Width (mm)	Depth (mm)	Height (mm)	Comments
1700	2300	200	Modified Large Furnace
1400	2300	900	Large Furnace

### Finishing:

Width (mm)	Depth (mm)	Height (mm)	Comments
2200	3000	300	CNC Machining Center
3000	5000	600	Surface Grinding



## Manufacturing Capabilities: MMC Products

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**Capacity and capability exists at DE facility to produce small to large size products for precision applications.**

1.5 m x 1.5 m  
Furnace

2.4 m x 4.4 m  
Furnace



- Large size castings to 2.2m<sup>2</sup>
- Furnace expandable to produce 3.2m<sup>2</sup> products.
- Finish machining capability in CT facility or via subcontract for large structures.



## Finishing Capability for Large Structures

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### Vertical Center:

- Cube : 1m x 2m x .9m
- Angular rotary positioning of .0001 deg. (.36 arc sec.) accuracy to 10 arc sec.
- Resolution: 1um with .4um repeatability
- Squareness to 2um in 500mm travel



### Horizontal Center:

- Cube : 1.2m x 1m x 1.1m
- Angular rotary positioning of .001 deg. (3.6 arc sec.) accuracy to 60 arc sec.
- Resolution: 1um with .4um repeatability
- Squareness to 4um in 700mm travel



- Additional capacity for large structures available via outsourcing.





## Finishing and Metrology Capability

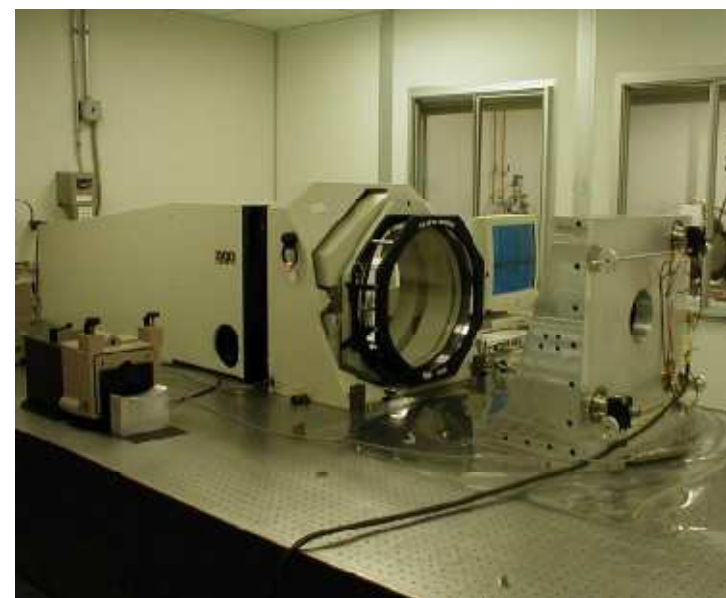
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CT Facility has capability and equipment to produce a wide range of high performance products that require precision tolerances and flatness.

- Multiple CNC machining centers
- Surface grinding
- EDM
- Multiple lapping machines for precision flatness.
- Clean Rooms for final assembly and Metrology.
- 450 and 300mm Zygo™ Phase Shift Interferometry.
- Zygo New View 200 Scanning White Light Interferometer for surface profiling.



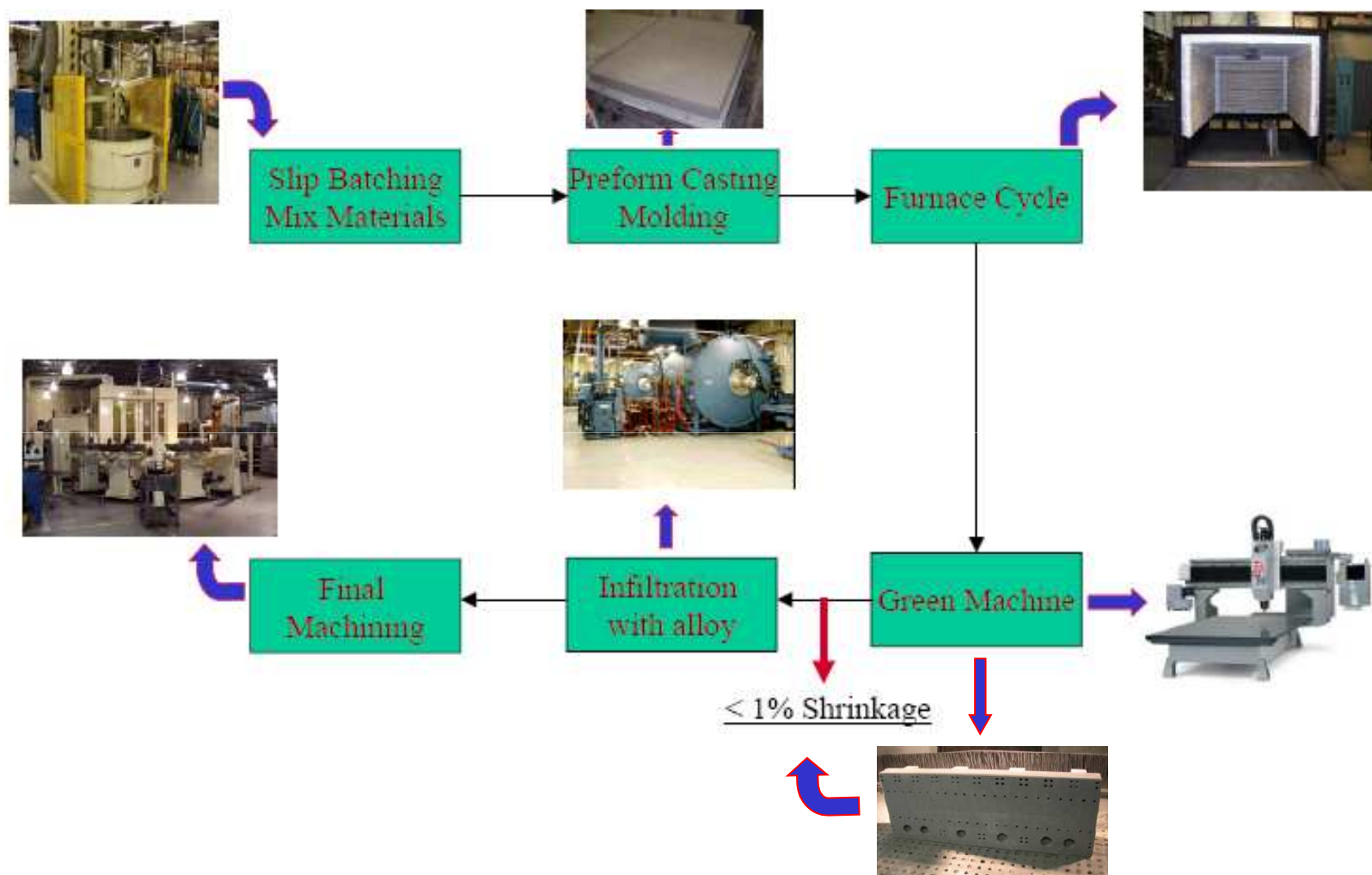
Multiple CMMs and support equipment for final inspection and qualification







## Reaction Bonding: Process Overview





## High Specific Stiffness Composite Development

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- ♦ M Cubed Technologies developed two composite materials to complement existing materials portfolio.

Material Family	Process	Features	Status
<b>RBBC-751 (Si/SiC/B<sub>4</sub>C)</b>	Reaction Bonding	Very high specific stiffness & low density. Large size capability for precision and optical structures	Full Production Capability..
<b>RBSC (Si/SiC) + Diamond</b>	Reaction Bonding	Ultra high specific stiffness. Very high thermal conductivity & low CTE for precision and optical structures.	Pilot line running. M Cubed technologies accepts orders on case by case basis.

Material properties of RBBC –751 and RBSC + diamond will be discussed in the following slides.



## Composite Properties:

M Cubed Grade	Density (g/cc)	Young's Modulus (GPa)	Specific Stiffness (GPa/g/cc)	Thermal Conduct. @RT (W/mk)	CTE, 20 to 100°C (ppm/K)	Thermal Stability (W/mK/ppm /K)	Flexural Strength (MPa)	Specific Strength (MPa/g/cc)	Fracture Toughness (MPa m <sup>1/2</sup> )
<b>Properties of Be for Comparison - Reference Data</b>									
* Beryllium(S-200F)	1.85	303	164	146	12	12	324	175	9 to 13
* BeAl Alloy (#363)	2.16	207	96	105	14	8	290	134	N/A
* AlBeMet162	2.1	196	93	212	14	15	305	145	9 to 13
<b>Reaction Bonded Boron Carbide (Si/SiC/B<sub>4</sub>C): Material has extremely high specific stiffness</b>									
<b>RBBC-751 (B<sub>4</sub>C/Si/SiC)</b>	2.56	400	148	52	4.8	11	280	109	5
<b>Diamond Reinforced Reaction Bonded SiC</b>									
<b>RBSC (Si/SiC)-40 vol.% Diamond</b>	3.27	580	177	380	1.8	211	N/A	N/A	N/A

Material properties of RBBC –751 and RBSC + diamond compares favorable with Be and Be-alloys.



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## Reaction Bonded Boron Carbide – (RBBC –751)

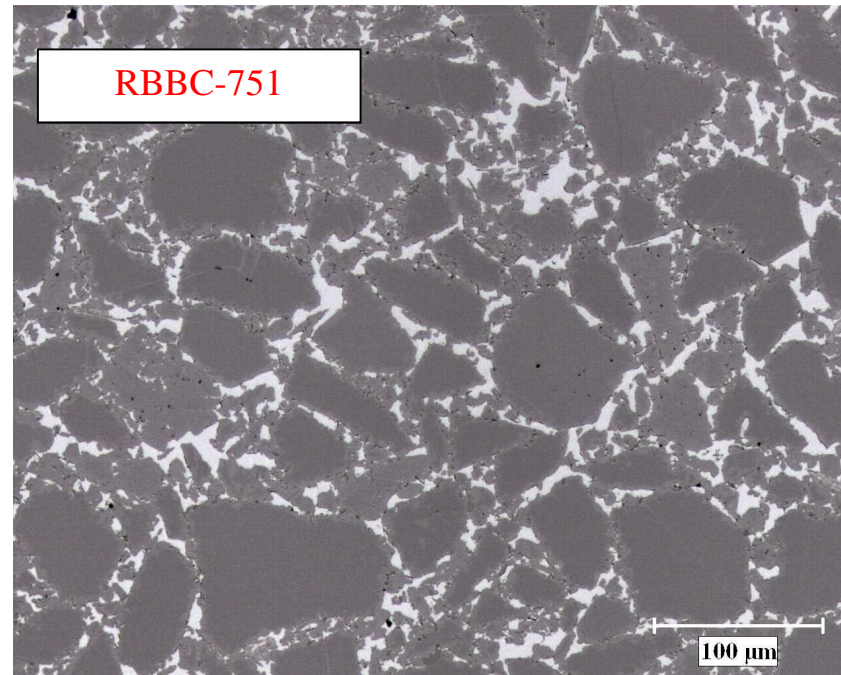
- ◆ Features very high specific stiffness due to high Young's modulus (400 GPa) and low density (2.56 g/cc)
- ◆ Composite is suitable for manufacturing of large pieces such as optical structures, precision stages & optical mirrors.



## Reaction Bonded $B_4C$ – RBBC- 751

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### M Cubed's RBBC - 751 Ceramics



- As a result of the high stiffness and low density of  $B_4C$ , its addition to an Si/SiC ceramic leads to a composite with very high specific stiffness.



## Reaction Bonded B<sub>4</sub>C Properties – Si-SiC/B<sub>4</sub>C

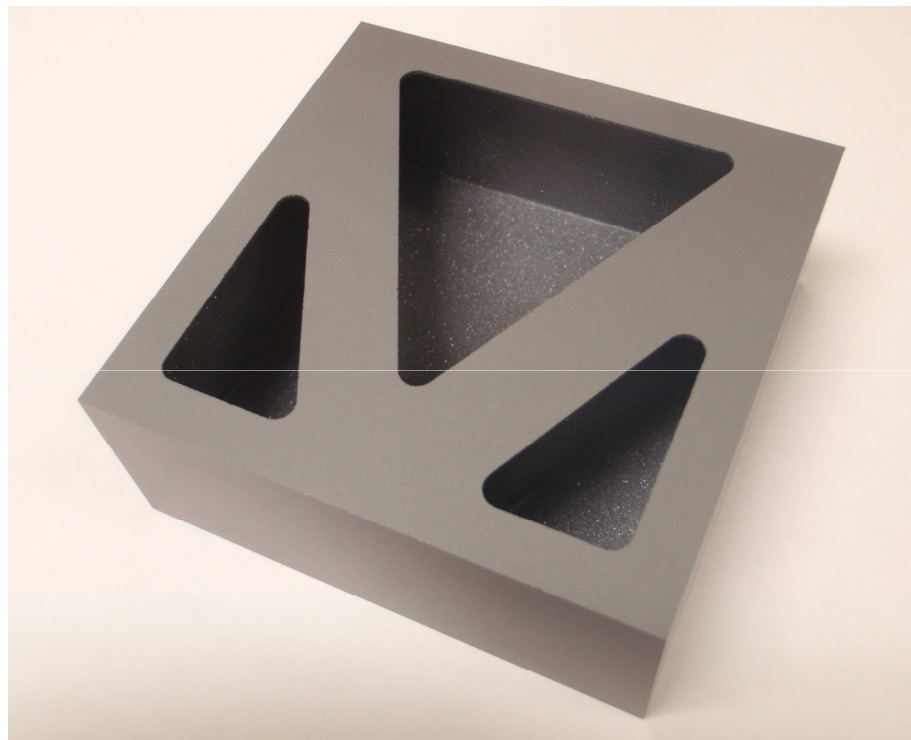
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Property	RBBC-751
Nominal Composition (vol. %)	75% B <sub>4</sub> C, 10% SiC, 15% Si
Density (g/cc)	2.56
Young's Modulus (GPa)	400
CTE at 20°C (ppm/K)	---
CTE ave from 20-100°C (ppm/K)	4.8
Thermal Conductivity (W/m-K)	50
Specific Heat (J/kg-K)	890
Knoop 2 kg Hardness (kg/mm <sup>2</sup> )	1550
Flexural Strength (MPa)	280
Fracture Toughness (MPa-m <sup>1/2</sup> )	5.0



## RBBC – 751: Product Examples

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Thin Walled Box Structure	RBBC-751
Nominal Composition (vol. %)	75% B <sub>4</sub> C, 10% SiC, 15% Si
Density (g/cc)	2.56
Young's Modulus (GPa)	400
Length (mm)	75
Width (mm)	75
Height (mm)	30
Wall thickness (mm)	1
Rib Thickness (mm)	1
Weight (g)	66.7





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## **RBSC + Diamond Materials**

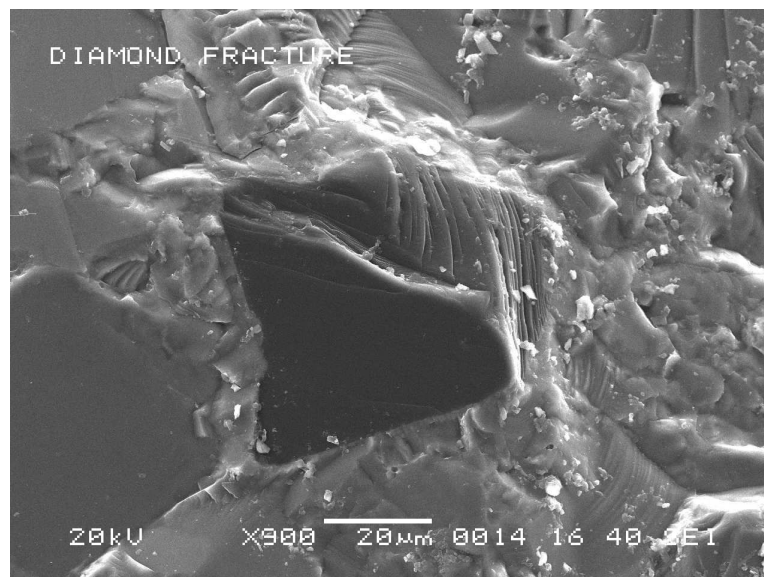
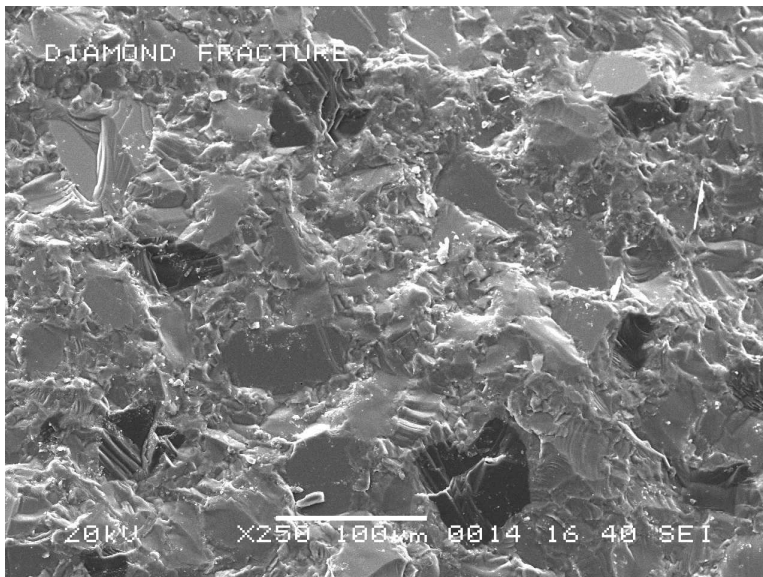
- ◆ Features very high thermal and mechanical stability due to high Young's modulus  $> 400$  GPa and thermal conductivity  $> 400$  W/mK.
- ◆ Composite is suitable for precision devices such as optical structures, stages and mirrors.



## Reaction Bonding of Si/SiC + Diamond Composites

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- ◆ Si/SiC and diamond composites can be manufactured using M Cubed standard reaction bonded process.
- ◆ Composites with 14 to 70 vol.% diamond with diamond particles size ranging from 6 to 65 micron have been successfully produced.

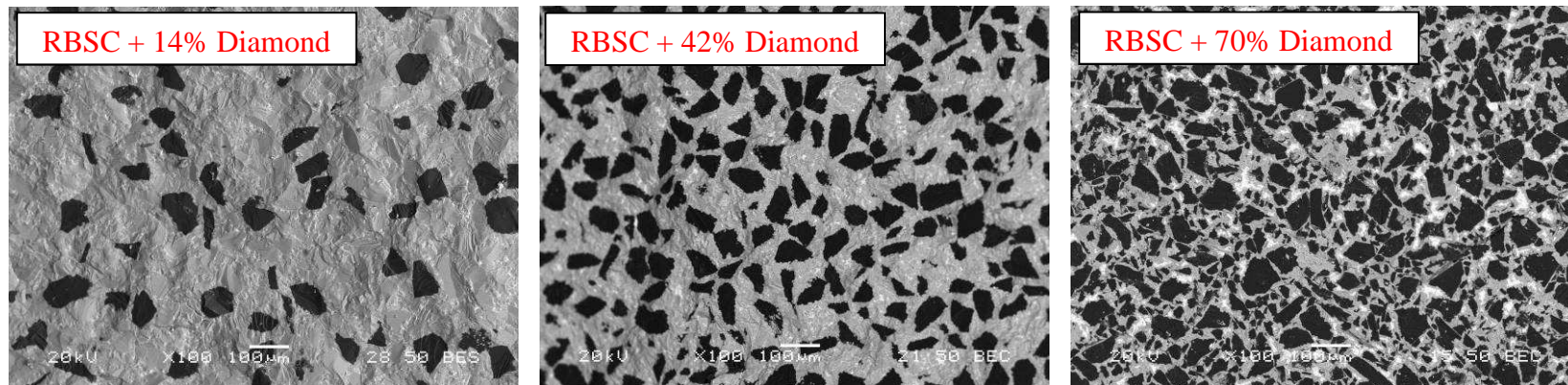




## RBSC + Diamond Composites (Si/SiC + Diamond)

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### Fracture Surfaces of M Cubed's RBSC + Diamond Composites



- Diamond has very attractive properties, including very high stiffness, very high thermal conductivity and very low CTE.
- As a result, the addition of diamond to RBSC yields composites with very high mechanical and thermal stability.



## RBSC + Diamond Properties - *Preliminary*

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Property	RBSC + 14% Diamond	RBSC + 42% Diamond	RBSC + 70% Diamond
Density (g/cc)	3.19	3.27	3.30
Young's Modulus (GPa)	490	580	700
CTE avg. from 20-100°C (ppm/K)	2.1	1.8	1.4
Thermal Conductivity (W/m-K)	270	380	625

- ◆ While Si/SiC + diamond composites have very attractive properties, their applications requires development of machining technologies for these super hard composites.
- ◆ M Cubed developed processing technologies to form diamond free machineable surfaces on diamond reinforced RBSC composites.

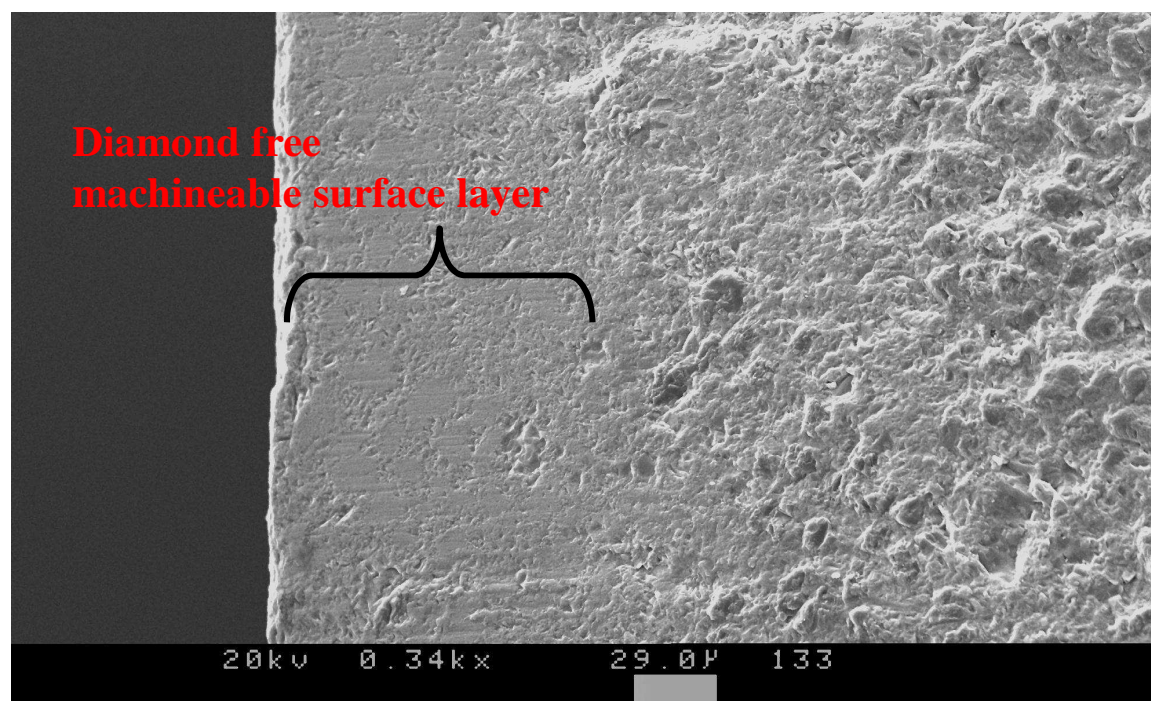




## Directly Polishable Thick Film Technology

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- ◆ Technology includes preferential decomposition of surface diamond particles to obtain SiC/Si surface chemistry.
- ◆ Technology has been successfully demonstrated (Patent Pending).

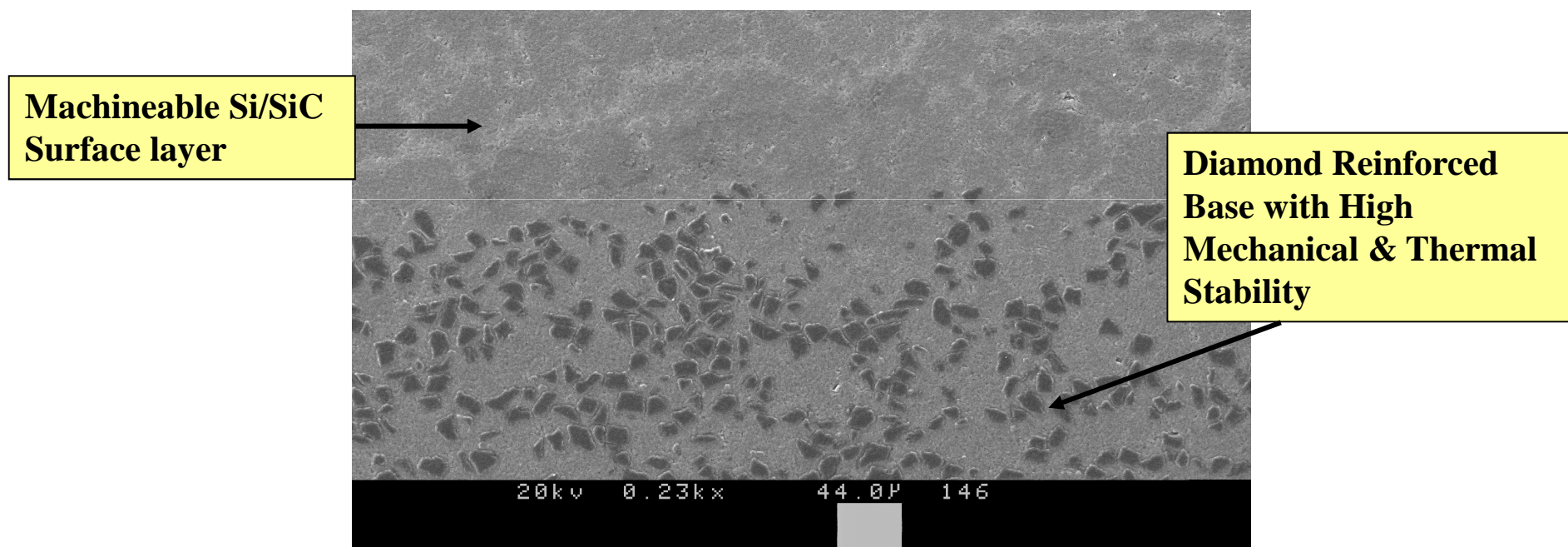




## Directly Polishable Thick Film Technology

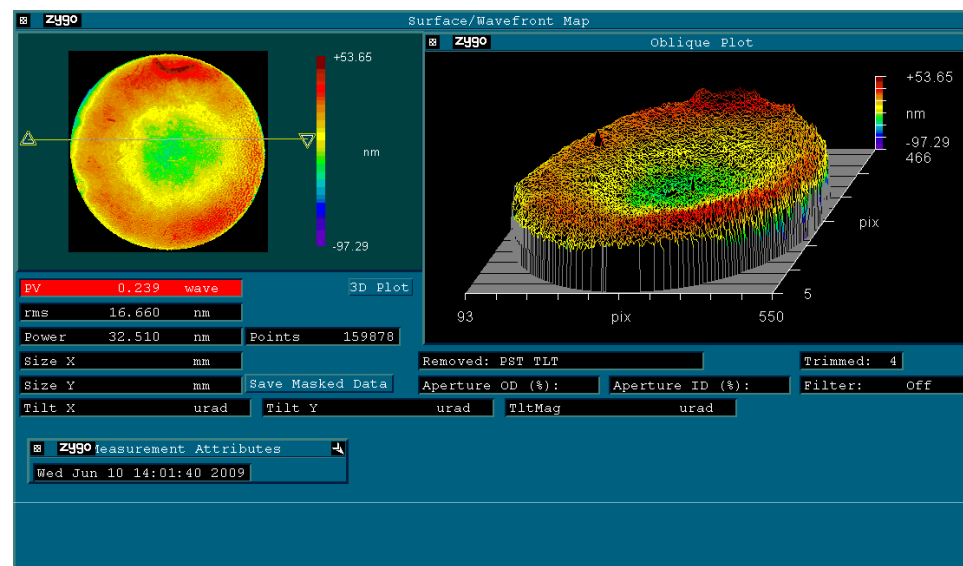
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- ◆ Technology includes coating of preform. Coated preform are then co-infiltrated to obtain monolithic composites.
- ◆ Technology has been successfully demonstrated (Patent Pending).





# Product Example: Directly Polishable Surfaces

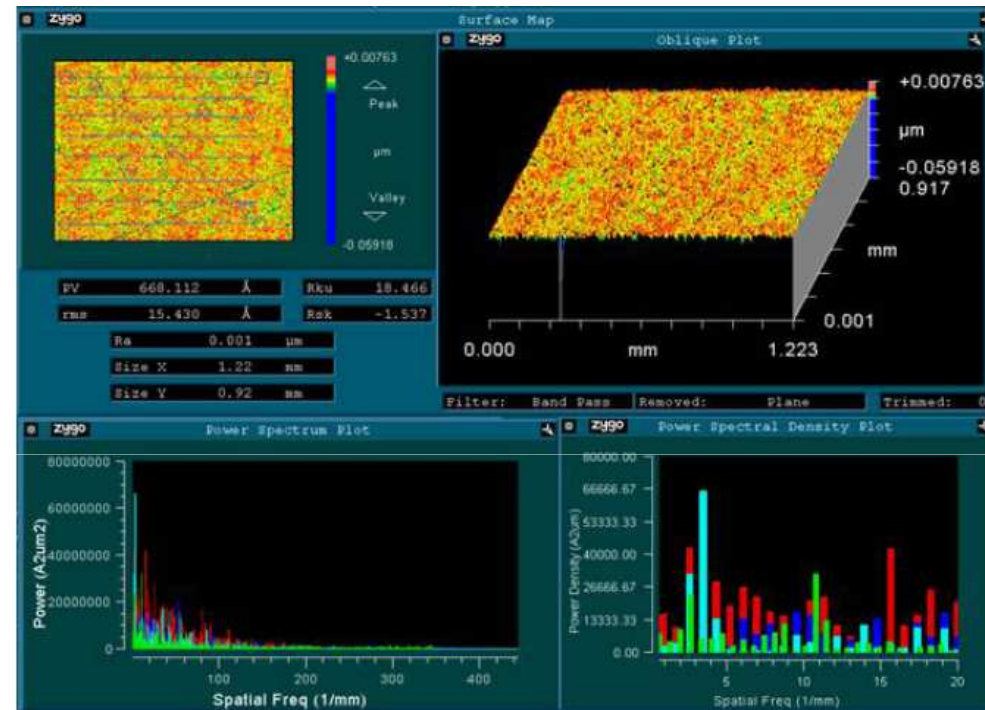


Laser Mirror Structure	RBBC-751
Base Composition (vol. %)	40%Diamond, 55% SiC, 5% Si
Density (g/cc)	3.27
Young's Modulus (GPa)	580
Coating	Si/SiC
Flatness	$\lambda/4$





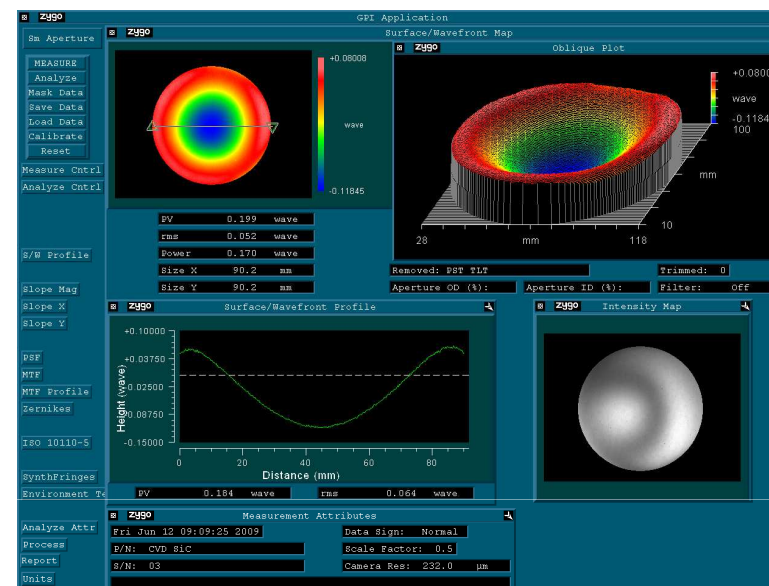
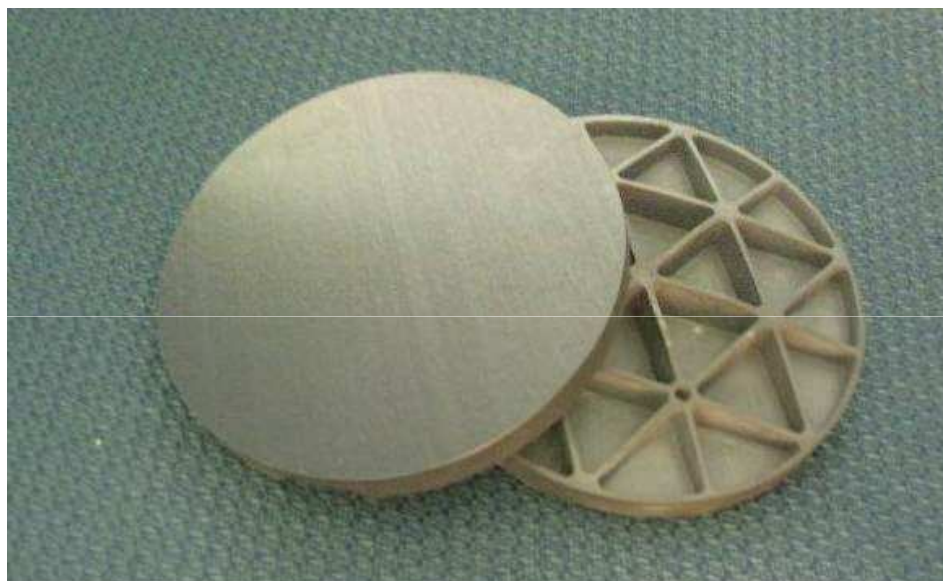
## Product Example: Directly Polishable Surfaces



<20A Average Surface Roughness Achieved with Conventional Grinding and Polishing



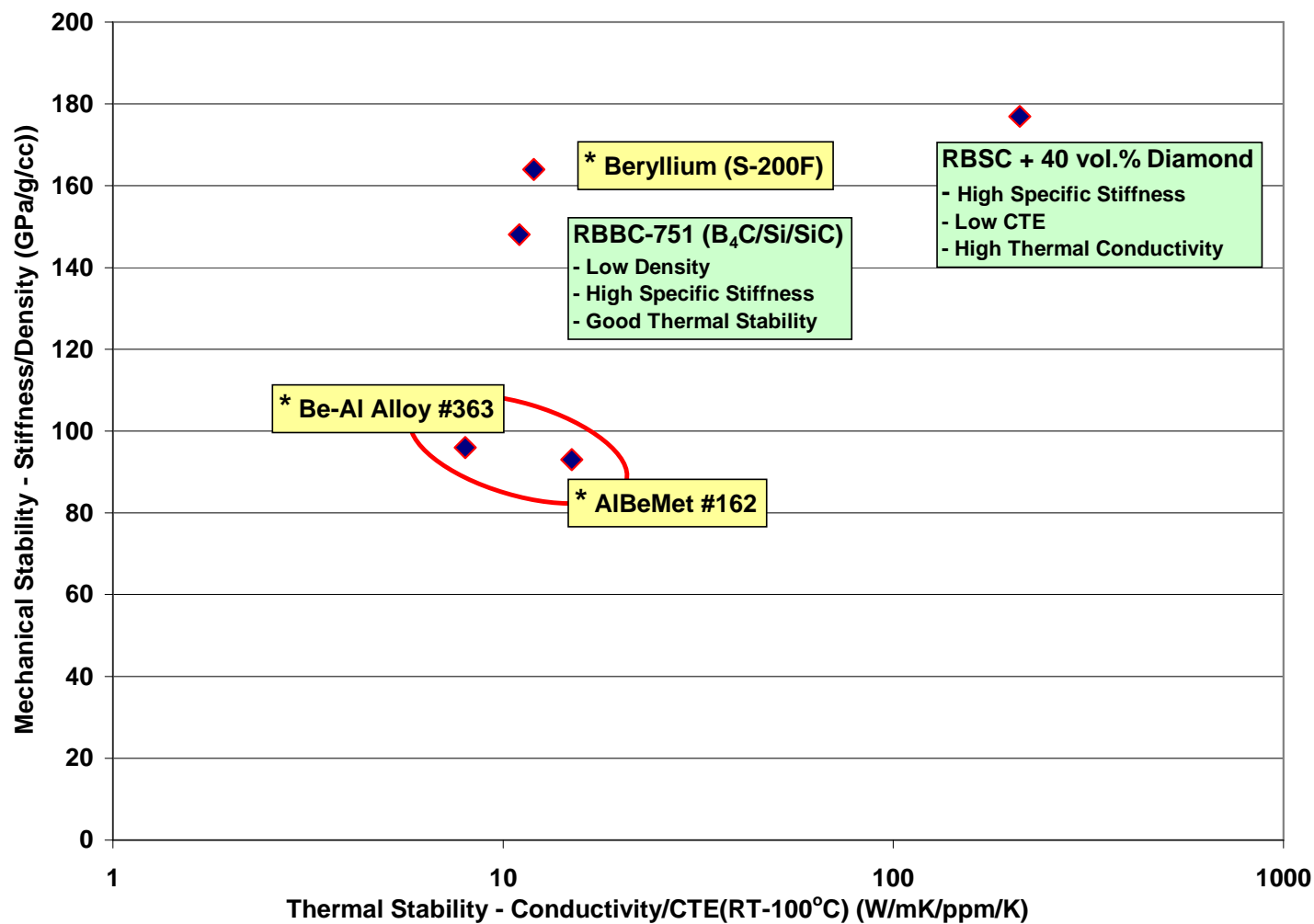
## Product Example: Coated Surfaces (Si Clad or CVD SiC)



Mirror Structure	RBBC-751
Base Composition (vol. %)	40%Diamond, 55% SiC, 5% Si
Density (g/cc)	3.27
Young's Modulus (GPa)	580
Coating	Si Clad
Flatness (PV)	$\lambda / 4$



# Thermal & Mechanical Stability Chart



\*Reference Data: Brush – Wellman Home Page



## Summary & Conclusions

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- ♦ M Cubed Technologies produces very high specific stiffness composites based on reaction bonded B<sub>4</sub>C and diamond reinforced SiC
- ♦ Diamond Reinforced Si/SiC composites combines ultra high specific stiffness with excellent thermal stability.
- ♦ Diamond reinforced composites surfaces can be tailored to enable machining & direct polishing.
- ♦ M Cubed is in full production with RBBC-751 and accepts orders for Diamond reinforced Si/SiC composites case by case basis.

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